DOCUMENT RESUME

ED 264 301 TM 860 009

AUTHOR Glaser, Robert
TITLE Thoughts on Expertise.
INSTITUTION Pittsburgh Univ., Pa. Learning Research and Development Center.
SPONS AGENCY National Inst. of Education (ED), Washington, DC.; Office of Naval Research, Arlington, Va. Personnel and Training Research Programs Office.
REPORT NO LRDC-TR-8
PUB DATE 1 May 85
CONTRACT N00014-71-C-0375; N00014-79-C-0215
NOTE 36p.; A version of a talk given at the Social Science Research Council conference on "The Study of Expertise as a Model for Life-Span Cognitive Development."
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Aptitude Tests; Artificial Intelligence; *Cognitive Development; Cognitive Processes; Cognitive Restructuring; Cognitive Structures; *Heuristics; *Metacognition; *Problem Solving; Schemata (Cognition)
IDENTIFIERS *Expertise

ABSTRACT

This paper briefly reviews research on tasks in knowledge-rich domains including developmental studies, work in artificial intelligence, studies of expert/novice problem solving, and information processing analysis of aptitude test tasks that have provided increased understanding of the nature of expertise. Particularly evident is the finding that expertise is acquired when people continually try to confront new situations in terms of what they know. Increasing ability to solve problems and generate new information is fostered by available knowledge that can be modified and restructured. Initial knowledge structures, when they are interrogated, instantiated, or falsified by novices in the course of learning and experience lead to organizations of knowledge that are the basis for the more complete schemata of experts. Acquiring expertise is seen as the successive development of procedurally oriented knowledge structures that facilitate the processes of expertise. A set of propositions is listed that summarizes conclusions from research as well as broader inferences and speculations. (PN)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Tech Rep. 8	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Learning Research and Development Center 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Personnel & Training Research Programs Office of Naval Research (Code 442PT)
6c. ADDRESS (City, State, and ZIP Code) University of Pittsburgh Pittsburgh, PA 15260	7b. ADDRESS (City, State, and ZIP Code) Arlington, VA 22217
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-78-C-0375 N00014-79-C-0215
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 157-421 / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Thoughts on Expertise

12. PERSONAL AUTHOR(S)
Robert Glaser

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM 10/1/80 TO 5/85	1 May 1985	21

16. SUPPLEMENTARY NOTATION
This research was also supported by the Learning Research and Development Center, with funds from the National Institute of Education (NIE), U. S. Department of Education.

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Acquisition of expertise
Aptitude test performance
Artificial intelligence
Cognitive skill acquisition
Domain-specific knowledge acquis.
Expert/novice problem solving
Heuristics, Metacognitive abilities

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Research on tasks in knowledge-rich domains including developmental studies, work in artificial intelligence, studies of expert/novice problem solving, and information-processing analyses of aptitude test tasks have provided increased understanding of the nature of expertise. Particularly evident is the finding that structures of organized knowledge enable the cognitive processes characteristic of high levels of competence. This paper briefly reviews this research and lists a set of propositions that summarize conclusions from research as well as broader inferences and speculations.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Susan E. Chipman	22b. TELEPHONE (Include Area Code) 202-696-4318 / 22c. OFFICE SYMBOL 442PT/85-157

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Thoughts on Expertise

Robert Glaser

Learning Research and Development Center

University of Pittsburgh

A version of a talk given at the Social Science Research Council conference on "The Study of Expertise as a Model for Life-Span Cognitive Development." The research reported in the paper was supported with funds from the Office of Naval Research, Personnel and Training Research Programs, Psychological Sciences Division under contract numbers N00014-78-C-0375, NR 157-421; N00014-79-C-0215, NR 147-430/12-19-80; and N00014-79-C-0215, NR 667-430.

General Remarks

Introduction

Information-processing studies of problem solving in the 1960s and 1970s accepted the tradition of early experimental psychology in concentrating primarily on the study of "knowledge-lean" tasks in which competence can usually be acquired over short periods of learning and experience. Studies of these tasks illuminated the basic information-processing capabilities people employ when they behave more and less intelligently in situations where they lack any specialized knowledge and skill. The pioneering work of Newell and Simon and others richly described general heuristic processes (such as means-end analysis, generate and test, and subgoal decomposition), but provided limited insight about the learning and thinking that require a rich structure of domain-specific knowledge.

In contrast to this, in more recent years, work has examined knowledge-rich tasks that require hundreds and thousands of hours of learning and experience in an area of study. Studies of expertise have attempted to sharpen this focus by describing contrasts between the performance of novices and experts. And the novices in these studies, e.g., intern radiologists, electronics technicians, etc., have engaged in learning over much longer periods than are required for short experimental tasks.

Investigations of problem solving in knowledge-rich domains show strong interactions between structures of knowledge and cognitive processes. The results force us to think about high levels of competence in terms of the interplay between knowledge structure and processing abilities. The data illuminate a critical difference between individuals who display more and less ability in particular domains of knowledge and skill, namely,

the possession of rapid access to and efficient utilization of an organized body of conceptual and procedural knowledge.

Data and theory in developmental psychology, studies of expert/novice problem solving, and process analyses of high and low scorers on intelligence and aptitude test tasks show that a major component of expertise is seen to be the possession of this accessible and usable knowledge.

Developmental Studies

As a warming up exercise (and to introduce a point of view), let me briefly mention some developmental studies with children. Chi, in several studies (Chi, 1978; Chi & Koeske, 1983), examined recall in children. She contrasted high- and low-knowledge children in chess skill and also children with high and low knowledge of dinosaur categories and features. Her results replicated in significant ways the early chess studies of DeGroot (1965), and of Chase and Simon (1973a, 1973b); high-knowledge subjects showed better memory and encoding performance than low-knowledge individuals. And this superiority was attributed to the influence of knowledge in content areas rather than to the exercise of memory capabilities as such. Changes in the knowledge base appear to enable sophisticated cognitive performance.

Susan Carey's studies of animistic thinking in young children (in press), trace the emergence of a child's concept of "alive." She documents a change, something like an expert/novice shift, from a knowledge organization centering around human characteristics (a novice point of view) to a knowledge organization centering around the biological functions of living things. Carey makes the point that what can be interpreted as abstract pervasive changes in a child's reasoning and learning abilities come about as knowledge is gained in a given domain.

The acquisition of content knowledge as a factor in acquiring increasingly sophisticated problem-solving abilities is pointed to in Siegler and Richards's "rule assessment" studies (1982). They conclude that "knowledge of specific content domains is a crucial dimension of development in its own right and that changes in such knowledge may underlie other changes previously attributed to the growth of capacities and strategies" (p. 930).

Artificial Intelligence

A focus on the structure of knowledge is also apparent in AI systems. In contrast to earlier emphases on general problem-solving techniques to guide a search for any problem--a power-based strategy--Minsky and Papert (1974) emphasize the role of a knowledge-base emphasis in achieving intelligent thinking. They write:

> The *Power* strategy seeks a generalized increase in computational power. . . . it may look toward extensions of deductive generality, or information retrieval, or search algorithms. . . . In each case the improvement sought is . . . independent of the particular data base.
>
> The *Knowledge* strategy sees progress as coming from better ways to express, recognize, and use diverse and particular forms of knowledge. . . . It is by no means obvious that very smart people are that way directly because of the superior power of their general methods--as compared with average people. . . . A very intelligent person might be that way because of specific local features of his knowledge-organizing knowledge rather than because of global qualities of his "thinking." (p. 59)

Expert/Novice Problem Solving

The work on problem solving in adult experts and novices has shown fairly consistent findings in quite a variety of domains--chess play, physics problem solving, the performance of architects and electronic technicians, and skilled radiologists interpreting x-rays. (I mention general conclusions only here but will provide more specific information in a final list of propositions about expertise.) This work has shown that relations between the structure of a knowledge base and problem-solving processes are mediated through the quality of representation of the problem. This problem representation is constructed by the solver on the basis of domain-related knowledge and the organization of this knowledge. The nature of this organization determines the quality, completeness, and coherence of the internal representation, which in turn determines the efficiency of further thinking.

Expert/novice research suggests that novices' representations are organized around the literal objects and events given explicitly in a problem statement. Experts' knowledge, on the other hand, is organized around inferences about principles and abstractions that subsume these factors. These principles are not apparent in the statement or the surface presentation of the problem. For example, in our studies with mechanics problems, novices classify problems on a surface level, according to the physical properties of a situation--a spring problem or an inclined plane problem. Experts categorize problems at a higher level, in terms of applicable physics principles--a Newton's second law problem, a conservation of energy problem.

In addition, experts know about the application of their knowledge. Their declarative information is tightly bound to conditions and procedures for its use. An intermediate

novice may have sufficient knowledge about a problem situation, but lack knowledge of conditions of applicability of this knowledge.

Consider a somewhat technical example. From protocols of novices and experts in solving elementary physics problems, we attempted to define the structure of their knowledge in the form of node-link networks (Chi, Glaser, & Rees, 1982). The nodes are key terms and physics concepts mentioned by the subjects. The links are unlabeled relations that join the concepts mentioned contiguously in the solver's protocol. The network of a novice's (H.P.) and an expert's (M.G.) elaboration of the concepts of an "inclined plane" problem are shown in Figure 1 and 2 respectively. We can view each of these concepts as representing a potential schema; the terms and concepts mentioned in the protocol can be thought of as the variables (slots) of the schema. For example, in Novice H.P.'s protocol, his inclined plane schema contains numerous variables that can be instantiated, including the angle at which the plane is inclined with respect to the horizontal, whether a block is resting on the plane, and the mass and height of the block. Other variables mentioned by the novice include the surface property of the plane, whether or not it has friction, and, if it does, the coefficients of static and kinetic friction. The novice also discusses possible forces that may act on the block, for example, the drag of a pulley. He also discusses the pertinence of Conservation of Energy, but this was not elicited as a part of a solution procedure applicable to a configuration involving an inclined plane, as is the case with the expert. Hence, in general, one could say that the inclined plane schema that the novice possesses is quite rich. He knows precisely what variables ought to be specified, and he also has default values for some of them. For example, if friction was not mentioned, he probably knows that he should ignore friction. Hence, with a simple specification that the problem is one

involving an inclined plane, he can deduce fairly accurately what the key components and entities are (i.e., friction) that such a problem would entail.

However, the casual reference to the underlying physics principle, Conservation of Energy, given by the novice contrasts markedly with the expert's protocol (Fig. 2). She immediately makes a call to two principles that take the status of procedures, the Conservation of Energy Principle and the Force Law. (In Greeno & Riley's, 1981, terminology, they would be considered calls to action schemata.) We characterize them as procedures (thus differentiating them from the way the novice mentioned a principle) because the expert, after mentioning the Force Law, continues to elaborate the condition of applicability of the procedure and then provides formulas for two of the conditions (enclosed in dashed rectangles in Fig. 2). After her elaboration of the principles and the conditions of applicability of one principle to inclined plane problems (depicted in the top half of Fig. 2), Expert M.G. continued her protocol with descriptions of the structural or surface features of inclined plane problems, much like the descriptions provided by Novice H.P. Hence, it seems that the knowledge common to subjects of both skill groups pertains to the physical configuration and its properties, but that the expert has additional knowledge relevant to the solution procedures based on major physics laws.

Another way of viewing the difference between the novice's and expert's elaborations of inclined plane is to look at Rumelhart's description (1981) of schemata of inactive objects. Here an inclined plane is seen by the novice as an inactive object, so that it evokes not actions or event sequences but spatial relationships and descriptions of the configuration and its properties. Experts, on the other hand, view an inclined plane in

the context of potential solution procedures, that is not as an object but more as an entity that may serve a particular function.

As in the developmental studies, the problem-solving "difficulties" of novices can be attributed largely to the nature of their knowledge bases, and much less to the limitations of their processing capabilities, such as their inability to use general problem-solving heuristics. Novices do show effective use of heuristics; the limitations of their thinking derive from their inability to infer further knowledge from the literal cues in a problem situation. These inferences are necessarily generated in the context of a knowledge structure that experts have acquired.

In general, study of problem solving by highly competent people in rich knowledge domains provides a glimpse of the power of human thinking to use a large knowledge system in an efficient and automatic manner--particularly in ways that minimize reliance on the search heuristics identified in studies of knowledge-lean problems. Thus, a significant focus for understanding expertise is identifying the characteristics and influence of organized knowledge structures that are acquired over long periods of time.

Aptitude Test Performance

Consider another converging area: process analyses of aptitude and intelligence test tasks performed by high- and low-scoring individuals. The evidence in this area comes from studies carried out by Earl Hunt and his colleagues (Hunt, 1978; Hunt, Frost, & Lunneborg, 1973), Robert Sternberg (1977b), and Pellegrino and Glaser (1982). My interpretation of several components of performance that differentiate high- and low-scoring individuals is the following: One component appears to involve rapid access to and management of working memory. The next two components appear to involve

specific knowledge. The first is conceptual knowledge of the item content. Low-scoring individuals with less available knowledge encode at surface feature levels rather than at levels of generalizable concepts; this limits their inferential ability. The second component is knowledge of the solution procedures required for solving a particular task form, such as analogical reasoning or induction items. Low-scoring individuals display a weak knowledge of procedural constraints that results in procedural bugs, and an inability to recover the goals of an analogy problem when they need to pursue subgoals of the task. This weak knowledge of procedural constraints sometimes allows them to turn a problem into an easier one to solve, such as a word association task. Such acquired knowledge, then, is suggested as a significant aspect of skillful aptitude test performance.

Schemata and Theories

The organizations of knowledge that are developed by experts can be thought of in terms of schemata or theories of knowledge. I define a schema here as a modifiable information structure that represents generic structures of concepts stored in memory. Schemata represent knowledge that we experience, i.e., interrelationships between objects, situations and events that occur. In this sense, schemata are prototypes in memory of frequently experienced situations that individuals use to integrate and interpret instances of related knowledge. Schema theory assumes that there are schemata for recurrent situations, and that these schemata enable people to construct interpretations, representations, and perceptions of situations.

If we think of a schema as a theory or internal model that is used, matched, and tested by individuals to instantiate the situations they encounter, like a scientific theory,

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☑ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Aug, J.

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

it is a source of representation and prediction. It enables individuals to impute meaning to a situation and to make inferences from information. As is the case for a scientific theory, if it fails to account for certain aspects of one's observations, it leads to learning that can modify or replace the theory. As a representation of a problem situation, it is accompanied by rules for solution of the problem.

Self-Regulation and General Skills

To temper my emphasis on structures of knowledge, I now point out that experts in various domains show self-regulatory or metacognitive capabilities that are not present in less mature or experienced learners. These abilities include knowing what one knows and doesn't know, planning ahead, efficiently apportioning one's time and attentional resources, and monitoring and editing one's efforts to solve a problem. To a large extent, I suspect that these self-regulatory activities are specific to a domain of knowledge in experts. Where they appear to be generalized competencies, i.e., in "generally intelligent" individuals, my hypothesis is that they become abstracted strategies after individuals use them in several fields of knowledge.

Perhaps widely competent children and adults, because of intensive exposure to different domains, employ skills that evolve as generalized cognitive processes. As general methods, however, these may be a small part of the intelligent performance shown by experts in specific fields of knowledge where they rapidly access acquired schemata and procedures. General processes may be important when an individual is confronted with problems in unfamiliar areas. However, future research may show that generalizable and transferable expertise lies in an ability to use familiar domains of knowledge for analogical and metaphorical thinking about new domains.

Generalisations

(1). There seems to be a continuous development of competence, as experience in a field accumulates. Eventual declines in competence may be the result of factors in the conditions of experience. Competence may be limited by the environment in which it is exercised. People may attain a level of competence only insofar as it is necessary to carry out the activities or to solve problems at the given level of complexity presented. Situations that extend competence may be less forthcoming as experts settle into their working situations.

(2). Expertise seems to be very specific. Expertise in one domain is no guarantee of expertise in other areas. It may be, however, that certain task domains are more generalizable than others, so that adults who are experts in applied mathematics or aesthetic design, or children when they learn measurement and number concepts, have forms of transferable expertise.

(3). Experts develop the ability to perceive large meaningful patterns. These patterns are seen in the course of their everyday activities. This pattern recognition occurs so rapidly that they take on the character of the "intuitions." In contrast, the patterns novices recognize are smaller, less articulated, more literal and surface oriented, and much less related to inferences and abstracted principles. The extraordinary representational ability of experts appears to depend on the nature and organization of knowledge existing in memory. As I indicated earlier, the fact that an expert has a more coherent, complete, functional and principled representation of knowledge than a novice necessarily implies an initial understanding of a problem that leads more easily to correct procedures and solutions.

(4). The knowledge of experts is highly procedural. Concepts are bound to procedures for their application, and to conditions under which these procedures are useful. The functional knowledge of experts is related strongly to their knowledge of the goal structure of a problem. Experts and novices may be equally competent at recalling small specific items of domain-related information. But high-knowledge individuals are much better at relating these events in cause-and-effect sequences that relate to the goal and subgoals of problem solution.

(5). These components of expertise enable fast-access pattern recognition and representational capability that facilitate problem perception in a way that greatly reduces the role of memory search and general processing. Novices, on the other hand, display a good deal of search and processing of a general nature. Their perceptions are highly literal and qualitatively different than representations of experts.

This picture of expertise is probably biased by the highly structured domains in which it has been studied, and the demands of situations in which cognitive expertise is acquired. How do experts solve problems in "ill-structured" domains? How do different experiences lead to different forms of expertise? Hatano (Hatano & Inagaki, 1983) distinguishes between routine (or conventional) expertise and adaptive expertise. Routine experts are outstanding in terms of speed, accuracy, and automaticity of performance, and construct mental models convenient for performing their tasks, but they lack adaptability to new problems. Probably, repeated application of a procedure with little variation leads to routine expertise. Adaptive expertise requires variation and is encouraged by playful situations and in cultures where understanding is valued along with efficient performance. Hatano speculates about how expertise might develop in an efficiency-oriented as compared with an understanding-oriented environment.

I sum up my thoughts about expertise in a set of propositions. These statements represent conclusions from research and occasional broader inferences and speculations.

A Pride of Propositions

1. Expertise is developed over hundreds and thousands of hours of learning and experience, and continues to develop. Studies have been carried on in many domains of work: chessmasters, scientists solving problems, radiologists, skilled technicians, abacus champions, people highly competent in sports, architecture planners, livestock judges, and dairy workers. (See Chi et al., 1982; and Chi, Glaser, & Farr, in press.)

2. In the course of acquiring expertise, plateaus and non-monotoniticies of development are observed which appear to indicate shifts in understanding and stabilizations of automaticity. Karmiloff-Smith (1984), Strauss and Stavy (1982), and Lesgold (1984) have suggested that novices and experts perform better than intermediates on problems that can be solved by surface-level representations.

3. Experts and novices work with similar capacity for processing; the outstanding performance of experts derives from how their knowledge is structured for processing.

4. Expert representations of problems and situations are qualitatively different than novice representations. In the course of developing expertise, problem representation changes from surface representations to inferred problem descriptions, to principled (and proceduralized) categorizations.

5. Expert representations (and schema instantiations) are like fast-access pattern recognitions that reduce processing load and the need for general search heuristics.

6. The representations of experts have actionable meaning; the knowledge of an expert is highly proceduralized and bound to conditions of the applicability of their knowledge.

7. In some domains, experts are "opportunistic planners"; new problem features result in changed problem representation; they show fast access to multiple possible interpretations; novices are less flexible. (E.g., x-ray and medical diagnosis, Lesgold, 1981).

8. Experts can be disarmed by random (or meaningless) patterns and lose their great perceptual ability. (E.g., with a scrambled chessboard experts and novices do equally poorly.)

9. Experts are schema specialized and these schemata drive their performance. (Experts impose a structure on a noisy x-ray; novices are misled by this noise.)

10. Experts are goal driven: given a complex goal, they will represent the problem accordingly; given simple goals, they will think only as deeply as necessary.

11. Experts display specific domain intelligence, not necessarily general intelligence.

12. Novices display good use of general heuristic problem-solving processes (of the Newell and Simon variety, e.g., generate and test, means-end analysis, subgoal decomposition); experts use them primarily in unfamiliar situations.

13. Experts may be slower than novices in initial problem encoding but are overall faster problem solvers. (E.g., analogical reasoning test items, Sternberg, 1977a.)

14. The development of expertise is subject to task demands and the "social structure" of the job situation; the cognitive models experts acquire are constrained by task requirements. (E.g., Scribner, 1984a, 1984b.)

15. Expertise in some knowledge domains may be more generalizable (broadly applicable) than other domains. (E.g., measurement concepts, number concepts, arithmetic problem-solving schema, Carey, in press.)

16. Experts develop automaticity (unconscious processing) particularly of "basic operations" so that working memory is available for necessary conscious processing. (E.g., efficient encoding processes in expert reading comprehenders, Perfetti & Lesgold, 1979.)

17. The experts' understanding may occur after extended practice with procedural skills. (E.g., Karmiloff-Smith, 1984; Strauss & Stavy, 1982.)

18. In solving ill-structured problems, experts employ relatively general methods of problem decomposition, subgoal conversion, and single factor analysis; their thinking is less immediately driven by principles and procedural aspects of their specific knowledge structures.

19. In ill-structured domains, experts work from their memory of an issue's history to represent problems and devise arguments for alternative solutions. (E.g., see analysis by political scientists, Voss, Greene, Post, and Penner, 1983.)

20. Experts develop skilled self-regulatory processes such as solution monitoring, allocation of attention, and sensitivity to informational feedback. (See Brown, 1978; and Gitomer & Glaser, in press.)

21. Expertise can be "routine" or "adaptive and reflective," depending upon the variety of experience and the culture in which it develops. (E.g., Hatano & Inagaki, 1983.)

22. Expert knowledge is not inert; it is highly proceduralized, conditionalized, and compiled. (Anderson, 1983.)

23. Super experts may develop generalizable abilities through the use of mapping and analogy from their own domain to others. (Gentner & Gentner, 1983.)

24. General thinking and problem-solving skills may develop in the course of shifting between many domains, so that the cognitive processes involved become decontextualized. (Glaser, 1984.)

Final Remarks

Increased understanding of the nature of expertise challenges us to inquire how it is learned. It seems evident that expertise is acquired when people continually try to confront new situations in terms of what they know. Increasing ability to solve problems and generate new information is fostered by available knowledge that can be modified and restructured. Thus, when teaching beginners we must build from initial knowledge structures. This might be accomplished by assessing and using relevant prior knowledge, or by providing obvious organizational schemes or temporary models as scaffolds for new information. These temporary "pedagogical theories" are regularly devised by ingenious instructors and could be incorporated more systematically into instruction. Such structures, when they are interrogated, instantiated or falsified by novices in the course of learning and experience lead to organizations of knowledge that are the basis for the more complete schemata of experts. Acquiring expertise is to be seen as the successive development of procedurally oriented knowledge structures that facilitate the processes of expertise.

References

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge: Harvard University Press.

Brown, A. L. (1978). Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 1). Hillsdale, NJ: Erlbaum.

Carey, S. (in press). Are children fundamentally different kinds of thinkers and learners than adults? In S. F. Chipman, J. W. Segal, & R. Glaser (Eds.), *Thinking and Learning Skills: Current research and open questions* (Vol. 2). Hillsdale, NJ: Erlbaum.

Chase, W. G., & Simon, H. A. (1973a). Perception in chess. *Cognitive Psychology, 4,* 55-81.

Chase, W. G., & Simon, H. A. (1973b). The mind's eye in chess. In W. G. Chase (Ed.), *Visual information processing.* New York: Academic Press.

Chi, M. T. H. (1978). Knowledge structures and memory development. In R. Siegler (Ed.), *Children's thinking: What develops?* (Vol. 1). Hillsdale, NJ: Erlbaum.

Chi, M. T. H., Glaser, R., & Farr, M. (in press). *The nature of expertise.* Hillsdale, NJ: Erlbaum.

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 1). Hillsdale, NJ: Erlbaum.

Chi, M. T. H. & Koeske, R. D. (1983). Network representation of a child's dinosaur knowledge. *Developmental Psychology, 19,* 29-39.

de Groot, A. (1965). *Thought and choice in chess.* The Hague: Mouton.

Gentner, D., & Gentner, D. R. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner & A. L. Stevens, *Mental models.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Gitomer, D. H., & Glaser, R. (in press). Knowledge, self-regulation and instruction. In R. E. Snow & M. J. Farr (Eds.), *Aptitude, learning, and instruction* (Vol. 3). Hillsdale, NJ: Erlbaum.

Glaser, R. (1984). Education and thinking. *American Psychologist, 39*(1), 93-104.

Greeno, J. G., & Riley, M. S. (1981). Processes and development of understanding. In F. E. Weinert & R. Kluwe (Eds.), *Learning by thinking.* Stuttgart, West Germany: Kohlhammer.

Hatano, G., & Inagaki, K. (1983, April). *Two courses of expertise.* Paper presented at the Conference on Child Development in Japan and the United States, Stanford, CA.

Hunt, E. (1978). Mechanics of verbal ability. *Psychological Review, 85,* 109-130.

Hunt, E., Frost, N., & Lunneborg, C. (1973). Individual differences in cognition: A new approach to intelligence. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 7). New York: Academic Press.

Karmiloff-Smith, A. (1984, June). *The human capacity for multiple representation and its relevance to developmental change.* Paper presented at the conference of the National Academy of Education, Lidingo, Sweden.

Lesgold, A. M. (1984). Acquiring expertise. In J. R. Anderson & S. M. Kosslyn (Eds.), *Tutorials in learning and memory: Essays in honor of Gordon Bower.* San Francisco: W. H. Freeman.

Lesgold, A. M., Feltovich, P. J., Glaser, R., & Wang, Y. (1981). *The acquisition of perceptual diagnostic skill in radiology* (Tech. Rep. PDS-1). Pittsburgh, PA: University of Pittsburgh, Learning Research and Development Center.

Minsky, M., & Papert, S. (1974). *Artificial intelligence.* Condon Lectures, Oregon State System of Higher Education, Eugene, Oregon.

Pellegrino, J. W., & Glaser, R. (1982). Analyzing aptitudes for learning: Inductive reasoning. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 2). Hillsdale, NJ: Erlbaum.

Perfetti, C. A., & Lesgold, A. M. (1979). Coding and comprehension in skilled reading. In L. B. Resnick & P. Weaver (Eds.), *Theory and practice of early reading.* Hillsdale, NJ: Erlbaum.

Rumelhart, D. E. (1981). Schemata: The building blocks of cognition. In R. Spiro, B. Bruce, & W. Brewer (Eds.), *Theoretical issues in reading comprehension.* Hillsdale, NJ: Erlbaum.

Scribner, S. (1984a). Cognitive studies of work. *Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 6*(1 & 2).

Scribner, S. (1984b). Studying working intelligence. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its development in social context.* Cambridge: Harvard University Press.

Siegler, R. S., & Richards, D. D. (1982). The development of intelligence. In R. J. Sternberg (Ed.), *Handbook of human intelligence.* Cambridge, England: Cambridge University Press.

Sternberg, R. (1977a). *Intelligence, information processing, and analogical reasoning: The componential analysis of human abilities.* Hillsdale, NJ: Erlbaum.

Sternberg, R. (1977b). Component processes in analogical reasoning. *Psychological Review, 84,* 353-378.

Strauss, S., & Stavy, R. (1982). U-shaped behavioral growth: Implications for theories of development. In W. W. Hartup (Ed.), *Review of child development research* (Vol. 6). Chicago: University of Chicago Press.

Voss, J. F., Greene, T. R., Post, T. A., & Penner, B. C. (1983). Problem solving skill in the social sciences. In G. Bower (Ed.), *The psychology of learning and motivation: Advances in research theory.* New York: Academic Press.

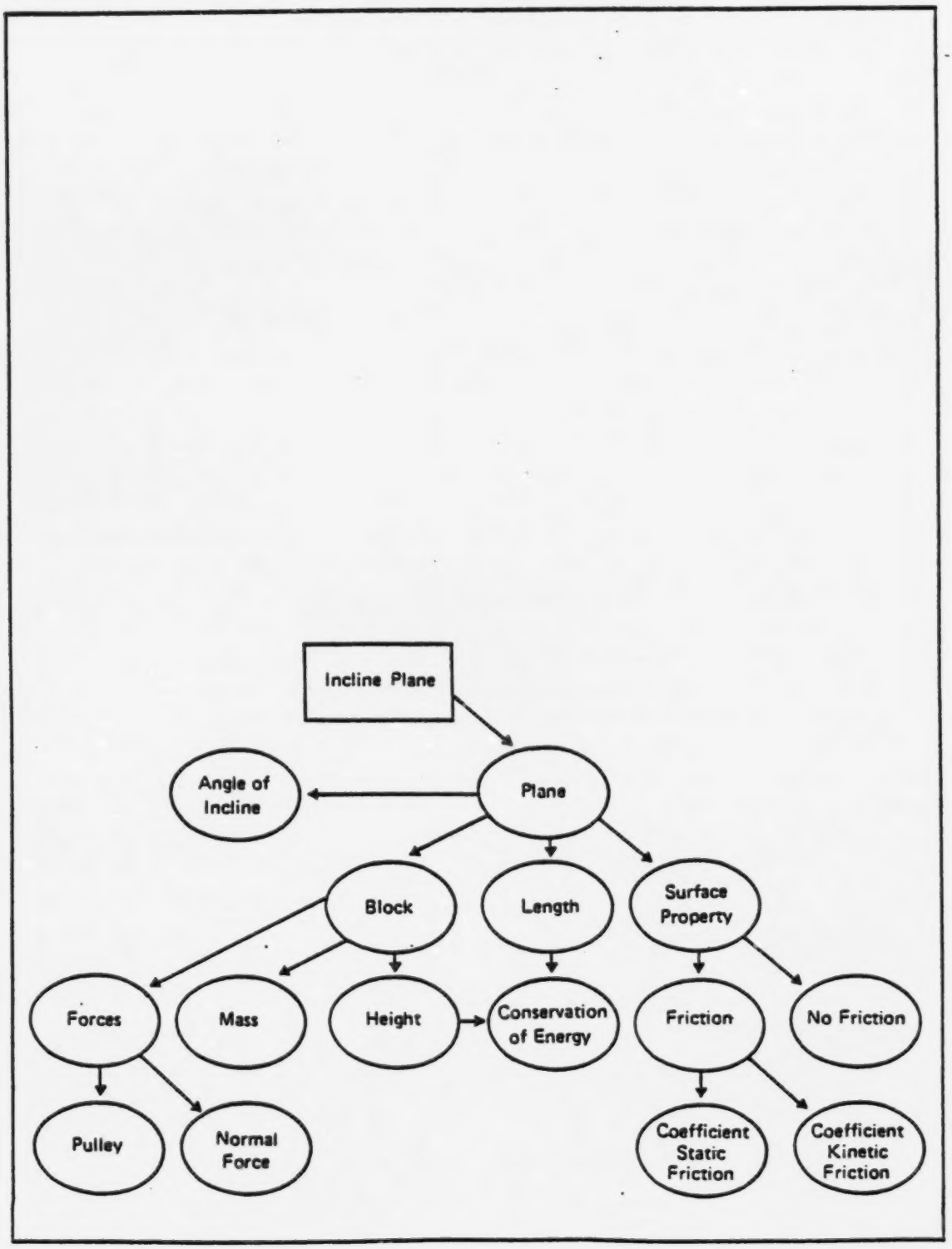

Figure 1. Network representation of Novice H.P.'s schema of an inclined plane.

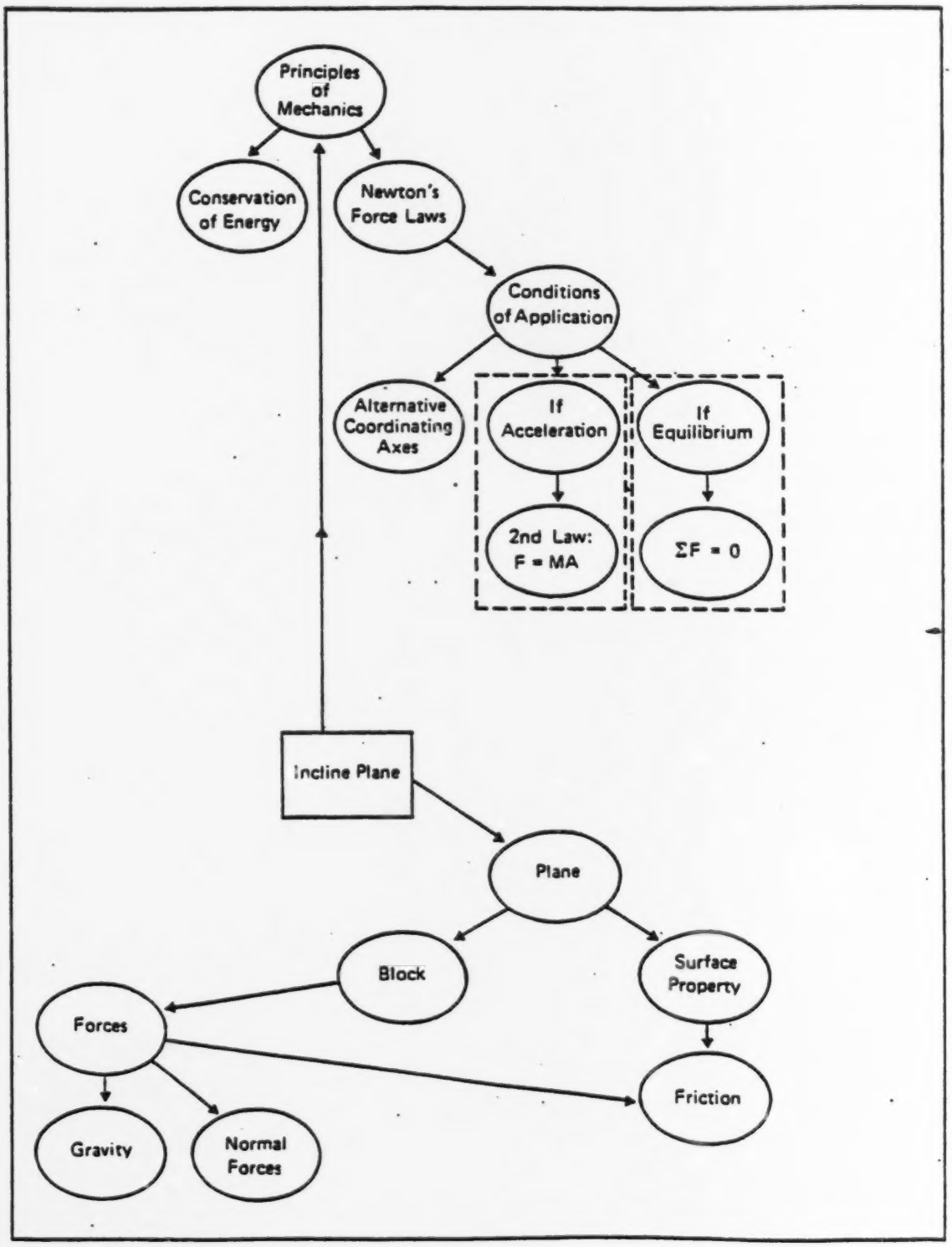

Figure 2. Network representation of Expert M.G.'s schema of an inclined plane.

Personnel Analysis Division
AF/MPXA
5C360, The Pentagon
Washington, DC 20330

Air Force Human Resources Lab
AFHRL/MPD
Brooks AFB, TX 78235

Air Force Office
of Scientific Research
Life Sciences Directorate
Bolling Air Force Base
Washington, DC 20332

Dr. Robert Ahlers
Code N711
Human Factors Laboratory
NAVTRAEQUIPCEN
Orlando, FL 32813

Dr. William E. Alley
AFHRL/MOT
Brooks AFB, TX 78235

Dr. Earl A. Alluisi
HQ, AFHRL (AFSC)
Brooks AFB, TX 78235

Dr. John R. Anderson
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

Dr. John Annett
University of Warwick
Department of Psychology
Coventry CV4 7AJ
ENGLAND

Technical Director
Army Research Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

Special Assistant for Projects
OASN(M&RA)
5D800, The Pentagon
Washington, DC 20350

Dr. Michael Atwood
ITT - Programming
1000 Oronoque Lane
Stratford, CT 06497

Dr. Patricia Baggett
University of Colorado
Department of Psychology
Boulder, CO 80309

Mr. J. Barber
HQS, Department of the Army
DAPE-ZBR
Washington, DC 20310

Capt. J. Jean Belanger
Training Development Division
Canadian Forces Training System
CFTSHQ, CFB Trenton
Astra, Ontario, K0K
CANADA

CDR Robert J. Biersner, USN
Naval Biodynamics Laboratory
P. O. Box 29407
New Orleans, LA 70189

Dr. Menucha Birenbaum
School of Education
Tel Aviv University
Tel Aviv, Ramat Aviv 69978
Israel

Dr. Werner Birke
Personalstammamt
der Bundeswehr
D-5000 Koeln 90
WEST GERMANY

Dr. Gautam Biswas
Department of Computer Science
University of South Carolina
Columbia, SC 29208

Dr. Alvah Bittner
Naval Biodynamics Laboratory
New Orleans, LA 70189

Dr. John Black
Yale University
Box 11A, Yale Station
New Haven, CT 06520

Code N711
Attn: Arthur S. Blaiwes
Naval Training Equipment Center
Orlando, FL 32813

Dr. Robert Blanchard
Navy Personnel R&D Center
San Diego, CA 92152

Mr. Arnold Bohrer
Psychological Research Section
Caserne Petits Chateau
CRS
1000 Brussels
BELGIUM

Dr. Jeff Bonar
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260

Dr. Nick Bond
Office of Naval Research
Liaison Office, Far East
APO San Francisco, CA 96503

Dr. Gordon H. Bower
Department of Psychology
Stanford University
Stanford, CA 94306

Dr. Richard Braby
TAEG
NAVTRAEQUIPCEN
Orlando, FL 32813

Dr. Robert Breaux
Code N-095R
NAVTRAEQUIPCEN
Orlando, FL 32813

Dr. John S. Brown
XEROX Palo Alto Research
Center
3333 Coyote Road
Palo Alto, CA 94304

Dr. Bruce Buchanan
Computer Science Department
Stanford University
Stanford, CA 94305

Dr. Patricia A. Butler
NIE Mail Stop 1806
1200 19th St.. NW
Washington, DC 20208

Dr. Robert Calfee
School of Education
Stanford University
Stanford, CA 94305

Col. Roger Campbell
AF/MPXOA
Pentagon, Room 4E195
Washington, DC 20330

Dr. Richard Cantone
Navy Research Laboratory
Code 7510
Washington, DC 20375

Dr. Jaime Carbonell
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Mr. Jim Carey
Coast Guard G-PTE
2100 Second St.. S.W.
Washington, DC 20593

Dr. Susan Carey
Harvard Graduate School of
Education
337 Gutman Library
Appian Way
Cambridge, MA 0138

Dr. Pat Carpenter
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Dr. Robert Carroll
NAVOP 01B7
Washington, DC 20370

Dr. Davida Charney
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Dr. Eugene Charniak
Brown University
Computer Science Department
Providence, RI 02912

Dr. Michelene Chi
Learning R & D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Mr. Raymond E. Christal
AFHRL/MOE
Brooks AFB, TX 78235

Dr. William Clancey
Computer Science Department
Stanford University
Stanford, CA 94306

Director
Manpower Support and
Readiness Program
Center for Naval Analysis
2000 North Beauregard Street
Alexandria, VA 22311

Scientific Advisor
to the DCNO (MPT)
Center for Naval Analysis
2000 North Beauregard Street
Alexandria, VA 22311

Chief of Naval Education
and Training
Liaison Office
Air Force Human Resource Laboratory
Operations Training Division
Williams AFB, AZ 85224

Assistant Chief of Staff
Research, Development,
Test, and Evaluation
Naval Education and
Training Command (N-5)
NAS Pensacola, FL 32508

Dr. Michael Cole
University of California
at San Diego
Laboratory of Comparative
Human Cognition - D003A
La Jolla, CA 92093

Dr. Allan M. Collins
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Stanley Collyer
Office of Naval Technology
800 N. Quincy Street
Arlington, VA 22217

Dr. Lynn A. Cooper
Learning R&D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Dr. Meredith P. Crawford
American Psychological Association
Office of Educational Affairs
1200 17th Street, N.W.
Washington, DC 20036

Dr. Hans Crombag
University of Leyden
Education Research Center
Boerhaavelaan 2
2334 EN Leyden
The NETHERLANDS

Dr. Lee Cronbach
16 Laburnum Road
Atherton, CA 94205

Dr. Kenneth B. Cross
Anacapa Sciences, Inc.
P.O. Drawer Q
Santa Barbara, CA 93102

CDR Mike Curran
Office of Naval Research
800 N. Quincy St.
Code 270
Arlington, VA 22217-5000

Bryan Dallman
AFHRL/LRT
Lowry AFB, CO 80230

Mr. Robert Denton
AFMPC/MPCYPR
Randolph AFB, TX 78150

Mr. Paul DiRenzo
Commandant of the Marine Corps
Code LBC-4
Washington, DC 20380

Dr. R. K. Dismukes
Associate Director for Life Sciences
AFOSR
Bolling AFB
Washington, DC 20032-6448

Dr. Emmanuel Donchin
University of Illinois
Department of Psychology
Champaign, IL 61820

Defense Technical
Information Center
Cameron Station, Bldg 5
Alexandria, VA 22314
Attn: TC
(12 Copies)

Barbara Eason
Military Educator's
Resource Network
InterAmerica Research Associates
1555 Wilson Blvd
Arlington, VA 22209

Edward E. Eddowes
CNATRA N301
Naval Air Station
Corpus Christi, TX 78419

Dr. John Ellis
Navy Personnel R&D Center
San Diego, CA 92252

Dr. Jeffrey Elman
University of California
Department of Linguistics
La Jolla, CA 92093

Dr. Richard Elster
Deputy Assistant Secretary
of the Navy (Manpower)
Washington, DC 20350

Dr. Randy Engle
Department of Psychology
University of South Carolina
Columbia, SC 29208

Lt. Col Rich Entlich
HQ, Department of the Army
OCSA(DACS-DPM)
Washington, DC 20310

ERIC Facility-Acquisitions
4833 Rugby Avenue
Bethesda, MD 20014

Dr. K. Anders Ericsson
University of Colorado
Department of Psychology
Boulder, CO 80309

Edward Esty
Department of Education, OERI
MS 40
1200 19th St., NW
Washington, DC 20208

Dr. Marshall J. Farr
2520 North Vernon Street
Arlington, VA 22207

Dr. Pat Federico
Code P13
NPRDC
San Diego, CA 92152

Dr. Paul Feltovich
Southern Illinois University
School of Medicine
Medical Education Department
P.O. Box 3926
Springfield, IL 62708

Mr. Wallace Feurzeig
Educational Technology
Bolt Beranek & Newman
10 Moulton St.
Cambridge, MA 02238

Dr. Craig I. Fields
ARPA
1400 Wilson Blvd.
Arlington, VA 22209

Dr. Gerhard Fischer
Liebiggasse 5/3
A 1010 Vienna
AUSTRIA

Dr. Dexter Fletcher
University of Oregon
Computer Science Department
Eugene, OR 97403

Dr. Ken Forbus
Department of Computer Science
University of Illinois
Champaign, IL 61820

Dr. Jude Franklin
Code 7510
Navy Research Laboratory
Washington, DC 20375

Dr. Carl H. Frederiksen
McGill University
3700 McTavish Street
Montreal, Quebec H3A 1Y2
CANADA

Dr. John R. Frederiksen
Bolt Beranek & Newman
50 Moulton Street
Cambridge, MA 02138

Dr. Norman Frederiksen
Educational Testing Service
Princeton, NJ 08541

Dr. Alfred R. Fregly
AFOSR/NL
Bolling AFB, DC 20332

Dr. Bob Frey
Commandant (G-P-1/2)
USCG HQ
Washington, DC 20593

Dr. Alinda Friedman
Department of Psychology
University of Alberta
Edmonton, Alberta
CANADA T6G 2E9

Dr. R. Edward Geiselman
Department of Psychology
University of California
Los Angeles, CA 90024

Dr. Michael Genesereth
Stanford University
Computer Science Department
Stanford, CA 94305

Dr. Dedre Gentner
University of Illinois
Department of Psychology
603 E. Daniel St.
Champaign, IL 61820

Dr. Robert Glaser
Learning Research
& Development Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15260

Dr. Marvin D. Glock
217 Stone Hall
Cornell University
Ithaca, NY 14853

Dr. Joseph Goguen
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Dr. Daniel Gopher
Industrial Engineering
& Management
TECHNION
Haifa 32000
ISRAEL

Dr. Sherrie Gott
AFHRL/MODJ
Brooks AFB, TX 78235

Jordan Grafman, Ph.D.
Department of Clinical
Investigation
Walter Reed Army Medical Center
6825 Georgia Ave., N. W.
Washington, DC 20307-5001

Dr. Wayne Gray
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Robert Glaser, "Thoughts on Expertise"

Dr. James G. Greeno
University of California
Berkeley, CA 94720

H. William Greenup
Education Advisor (E031)
Education Center, MCDEC
Quantico, VA 22134

Ms. Glenda Greenwald, Editor
Human Intelligence Newsletter
P. O. Box 1163
Birmingham, MI 48012

Dipl. Pad. Michael W. Habon
Universitat Dusseldorf
Erziehungswissenschaftliches
Universitatsstr. 1
D-4000 Dusseldorf 1
WEST GERMANY

Dr. Henry M. Halff
Halff Resources, Inc.
4918 33rd Road, North
Arlington, VA 22207

Dr. Reid Hastie
Northwestern University
Department of Psychology
Evanston, IL 60201

Dr. Harold Hawkins
Department of Psychology
University of Oregon
Eugene, OR 97403

Dr. Barbara Hayes-Roth
Department of Computer Science
Stanford University
Stanford, CA 95305

Dr. Frederick Hayes-Roth
Teknowledge
525 University Ave.
Palo Alto, CA 94301

Dr. Joan I. Heller
Graduate Group in Science and
Mathematics Education
c/o School of Education
University of California
Berkeley, CA 94720

Dr. Jim Hollan
Code 51
Navy Personnel R & D Center
San Diego, CA 92152

Dr. Keith Holyoak
University of Michigan
Human Performance Center
330 Packard Road
Ann Arbor, MI 48109

Prof. Lutz F. Hornke
Universitat Dusseldorf
Erziehungswissenschaftliches
Universitatsstr. 1
Dusseldorf 1
WEST GERMANY

Mr. Dick Hoshaw
NAVOP-135
Arlington Annex
Room 2834
Washington, DC 20350

Dr. Steven Hunka
Department of Education
University of Alberta
Edmonton, Alberta
CANADA

Dr. Earl Hunt
Department of Psychology
University of Washington
Seattle, WA 98105

Dr. Ed Hutchins
Navy Personnel R&D Center
San Diego, CA 92152

Dr. Zachary Jacobson
Bureau of Management Consulting
365 Laurier Avenue West
Ottawa, Ontario K1A 0S5
CANADA

Dr. Marcel Just
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Daniel Kahneman
The University of British Columbia
Department of Psychology
#154-2053 Main Mall
Vancouver, British Columbia
CANADA V6T 1Y7

Dr. Milton S. Katz
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Norman J. Kerr
Chief of Naval Education
and Training
Code 00A2
Naval Air Station
Pensacola, FL 32508

Dr. David Kieras
University of Michigan
Technical Communication
College of Engineering
1223 E. Engineering Building
Ann Arbor, MI 48109

Dr. Walter Kintsch
Department of Psychology
University of Colorado
Boulder, CO 80302

Dr. David Klahr
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Mazie Knerr
Program Manager
Training Research Division
HumRRO
1100 S. Washington
Alexandria, VA 22314

Dr. Janet L. Kolodner
Georgia Institute of Technology
School of Information
& Computer Science
Atlanta, GA 30332

Dr. Stephen Kosslyn
Harvard University
1236 William James Hall
33 Kirkland St.
Cambridge, MA 02138

Dr. Pat Langley
University of California
Department of Information
and Computer Science
Irvine, CA 92717

Dr. Marcy Lansman
University of North Carolina
The L. L. Thurstone Lab.
Davie Hall 013A
Chapel Hill, NC 27514

Dr. Jill Larkin
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Dr. Robert Lawler
Information Sciences, FRL
GTE Laboratories, Inc.
40 Sylvan Road
Waltham, MA 02254

Dr. Alan M. Lesgold
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260

Dr. Jim Levin
University of California
Laboratory for Comparative
Human Cognition
D003A
La Jolla, CA 92093

Dr. Clayton Lewis
University of Colorado
Department of Computer Science
Campus Box 430
Boulder, CO 80309

Dr. Don Lyon
P. O. Box 44
Higley, AZ 85236

Robert Glaser, "Thoughts on Expertise"

Dr. William L. Maloy (02)
Chief of Naval Education
and Training
Naval Air Station
Pensacola, FL 32508

Dr. Sandra P. Marshall
Department of Psychology
University of California
Santa Barbara, CA 93106

Dr. Manton M. Matthews
Department of Computer Science
University of South Carolina
Columbia, SC 29208

Dr. Richard E. Mayer
Department of Psychology
University of California
Santa Barbara, CA 93106

Dr. Jay McClelland
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

Dr. Barbara Means
Human Resources
Research Organization
1100 South Washington
Alexandria, VA 22314

Dr. Arthur Melmed
724 Brown
U. S. Department of Education
Washington, DC 20208

Dr. Al Meyrowitz
Office of Naval Research
Code 433
800 N. Quincy
Arlington, VA 22217-5000

Dr. Andrew R. Molnar
Scientific and Engineering
Personnel and Education
National Science Foundation
Washington, DC 20550

Dr William Montague
NPRDC Code 13
San Diego, CA 92152

Dr. Tom Moran
Xerox PARC
3333 Coyote Hill Road
Palo Alto, CA 94304

Headquarters, Marine Corps
Code MPI-20
Washington, DC 20380

Dr. Allen Munro
Behavioral Technology
Laboratories
1845 Elena Ave.
Redondo Beach, CA 90277

Lt. Col. Jim Murphy
HQ, Marine Corps
Code MRRP
Washington, DC 20380

Director
Overseas Duty Support Program
Naval Military Personnel Command
N-62
Washington, DC 20370

Head, HRM Operations Branch
Naval Military Personnel Command
N-62F
Washington, DC 20370

Assistant for Evaluation,
Analysis, and MIS
Naval Military Personnel Command
N-6C
Washington, DC 20370

Spec. Asst. for Research, Experi-
mental & Academic Programs
Naval Technical Training Command
(Code 016)
NAS Memphis (75)
Millington, TN 38054

Program Manager for Manpower,
Personnel, and Training
NAVMAT 0722
Arlington, VA 22217-5000

Assistant for Long Range
Requirements
CNO Executive Panel (NAVOP 00K)
2000 North Beauregard Street
Alexandria, VA 22311

Assistant for Planning MANTRAPERS
NAVOP 01B6
Washington, DC 20370

Assistant for MPT Research,
Development and Studies
NAVOP 01B7
Washington, DC 20370

Head
Manpower, Personnel, Training
and Reserve Team
NAVOP 914D
5A578, The Pentagon
Washington, DC 20350

Leadership Management Education
and Training Project Officer
Naval Medical Command (Code 05C)
Washington, DC 20372

Dr. Richard E. Nisbett
University of Michigan
Institute for Social Research
Room 5261
Ann Arbor, MI 48109

Dr. Donald A. Norman
Institute for Cognitive Science
University of California
La Jolla, CA 92093

Director, Training Laboratory
NPRDC (Code 05)
San Diego, CA 92152

Director, Manpower and Personnel
Laboratory
NPRDC (Code 06)
San Diego, CA 92152

Director
Human Factors
& Organizational Systems Lab.
NPRDC (Code 07)
San Diego, CA 92152

Library
Code P201L
Navy Personnel R&D Center
San Diego, CA 92152

Technical Director
Navy Personnel R&D Center
San Diego, CA 92152

Commanding Officer
Naval Research Laboratory
Code 2627
Washington, DC 20390

Dr. Harry F. O'Neil, Jr.
Training Research Lab
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Stellan Ohlsson
Learning R & D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Director Technology Programs
Office of Naval Research
Code 200
800 North Quincy Street
Arlington, VA 22217-5000

Director Research Programs
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217 5000

Office of Naval Research
Code 433
800 N. Quincy Street
Arlington, VA 22217-5000

Office of Naval Research
Code 442EP
800 N. Quincy Street
Arlington, VA 22217-5000

Office of Naval Research
Code 442PT
800 N. Quincy Street
Arlington, VA 22217-5000
(6 Copies)

Special Assistant for Marine
Corps Matters
Code 100M
Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217-5000

Psychologist
ONR Branch Office
1030 East Green Street
Pasadena, CA 91101

Commanding Officer
Army Research Institute
ATTN: PERI-BR (Dr. J. Orasanu)
5001 Eisenhower Avenue
Alexandria, VA 22333

Prof. Seymour Papert
20C-109
Massachusetts Institute
of Technology
Cambridge, MA 02139

Lt. Col. (Dr.) David Payne
AFHRL
Brooks AFB, TX 78235

Dr. Douglas Pearse
DCIEM
Box 2000
Downsview, Ontario
CANADA

Dr. James W. Pellegrino
University of California,
Santa Barbara
Department of Psychology
Santa Barbara, CA 93106

Dr. Nancy Pennington
University of Chicago
Graduate School of Business
1101 E. 58th St.
Chicago, IL 60637

Military Assistant for Training and
Personnel Technology
OUSD (R & E)
Room 3D129, The Pentagon
Washington, DC 20301

Dr. Martha Polson
Department of Psychology
Campus Box 346
University of Colorado
Boulder, CO 80309

Dr. Peter Polson
University of Colorado
Department of Psychology
Boulder, CO 80309

Dr. Harry E. Pople
University of Pittsburgh
Decision Systems Laboratory
1360 Scaife Hall
Pittsburgh, PA 15261

Dr. Joseph Psotka
ATTN: PERI-1C
Army Research Institute
5001 Eisenhower Ave.
Alexandria, VA 22333

Dr. Lynne Reder
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Dr. Fred Reif
Physics Department
University of California
Berkeley, CA 94720

Dr. Lauren Resnick
Learning R & D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Dr. Mary S. Riley
Program in Cognitive Science
Center for Human Information
Processing
University of California
La Jolla, CA 92093

Dr. William B. Rouse
Georgia Institute of Technology
School of Industrial & Systems
Engineering
Atlanta, GA 30332

Dr. David Rumelhart
Center for Human
Information Processing
Univ. of California
La Jolla, CA 92093

Dr. Robert Sasmor
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Roger Schank
Yale University
Computer Science Department
P.O. Box 2158
New Haven, CT 06520

Dr. Walter Schneider
University of Illinois
Psychology Department
603 E. Daniel
Champaign, IL 61820

Dr. Alan Schoenfeld
University of California
Department of Education
Berkeley, CA 94720

Dr. Judah L. Schwartz
MIT
20C-120
Cambridge, MA 02139

Dr. Marc Sebrechts
Department of Psychology
Wesleyan University
Middletown, CT 06475

Dr. Judy Segal
NIE
1200 19th Street N.W.
Mail Stop 1806
Washington, DC 20208

Dr. Sylvia A. S. Shafto
National Institute of Education
1200 19th Street
Mail Stop 1806
Washington, DC 20208

Mr. Colin Sheppard
Applied Psychology Unit
Admiralty Marine Technology Est.
Teddington, Middlesex
UNITED KINGDOM

Dr. Kazuo Shigemasu
7-9-24 Kugenuma-Kaigan
Fujusawa 251
JAPAN

Dr. Ted Shortliffe
Computer Science Department
Stanford University
Stanford, CA 94305

Dr. Lee Shulman
Stanford University
1040 Cathcart Way
Stanford, CA 94305

Dr. Robert S. Siegler
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Herbert A. Simon
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Dr. Zita M Simutis. Chief
Instructional Technology
Systems Area
ARI
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. H. Wallace Sinaiko
Manpower Research
and Advisory Services
Smithsonian Institution
801 North Pitt Street
Alexandria, VA 22314

Dr. Edward E. Smith
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Richard Snow
Liaison Scientist
Office of Naval Research
Branch Office, London
Box 39
FPO New York, NY 09510

Dr. Elliot Soloway
Yale University
Computer Science Department
P.O. Box 2158
New Haven, CT 06520

Dr. Kathryn T. Spoehr
Brown University
Psychology Department
Providence, RI 02912

James J. Staszewski
Research Associate
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Dr. Frederick Steinheiser
CIA-ORD
612 Ames
Washington, DC 20505

Dr. Robert Sternberg
Department of Psychology
Yale University
Box 11A, Yale Station
New Haven, CT 06520

Dr. Albert Stevens
Bolt Beranek & Newman, Inc.
10 Moulton St.
Cambridge, MA 02238

Dr. Paul J. Sticha
Senior Staff Scientist
Training Research Division
HumRRO
1100 S. Washington
Alexandria, VA 22314

Dr. Thomas Sticht
Navy Personnel R&D Center
San Diego, CA 92152

Dr. John Tangney
AFOSR/NL
Bolling AFB, DC 20332

Dr. Martin M. Taylor
DCIEM
Box 2000
Downsview, Ontario
CANADA

Dr. Perry W. Thorndyke
FMC Corporation
Central Engineering Labs
1185 Coleman Avenue, Box 580
Santa Clara, CA 95052

Dr. Martin A. Tolcott
Psychological Sciences Division
Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217-5000

Dr. Douglas Towne
Behavioral Technology Labs
1845 S. Elena Ave.
Redondo Beach, CA 90277

Dr. Amos Tversky
Stanford University
Dept. of Psychology
Stanford, CA 94305

Dr. James Tweeddale
Technical Director
Navy Personnel R&D Center
San Diego, CA 92152

Dr. Paul Twohig
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Headquarters, U. S. Marine Corps
Code MPI-20
Washington, DC 20380

Dr. Kurt Van Lehn
Xerox PARC
3333 Coyote Hill Road
Palo Alto, CA 94304

BEST COPY AVAILABLE

Dr. Beth Warren
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Dr. Keith T. Wescourt
FMC Corporation
Central Engineering Labs
1185 Coleman Ave., Box 580
Santa Clara, CA 95052

Dr. Barbara White
Bolt Beranek & Newman, Inc.
10 Moulton Street
Cambridge, MA 02238

Dr. Robert A. Wisher
U.S. Army Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Martin F. Wiskoff
Navy Personnel R & D Center
San Diego, CA 92152

Dr. Merlin C. Wittrock
Graduate School of Education
UCLA
Los Angeles, CA 90024

Mr. John H. Wolfe
Navy Personnel R&D Center
San Diego, CA 92152

Dr. Wallace Wulfeck, III
Navy Personnel R&D Center
San Diego, CA 92152

Dr. Joe Yasatuke
AFHRL/LRT
Lowry AFB, CO 80230

Mr. Carl York
System Development Foundation
181 Lytton Avenue
Palo Alto, CA 94301

Dr. Joseph L. Young
Memory & Cognitive
Processes
National Science Foundation
Washington, DC 20550

Dr. Steven Zornetzer
Office of Naval Research
Code 440
800 N. Quincy St.
Arlington, VA 22217-5000

BEST COPY AVAILABLE